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NAVAL POSTGRADUATE SCHOOL

Monterey, California

UNDERWATER DISPLAY VISIBILITY AS INFLUENCED

BY

TURBIDITY, VIEWING DISTANCE,

AND COLOR OF ILLUMINATION

By

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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ABSTRACT

The purpose of this study was to determine the effects of illumination color, viewing distance, and turbidity on a visual reading task in a totally dark, flooded environment. The reading task was to read a voltmeter and make a correct oral report of the reading. A total of 180 data points spread over 18 viewing conditions were taken for each subject. Seventeen military officers were used as subjects. Experimental conditions were presented in a random manner to all subjects. A statistical examination of the results showed that white or green illumination is better than red in reducing reading response time. Turbidity levels were significant in affecting response time showing an increased response time as the Attenuation Coefficient (α) increased. There was no difference in the effect of an eight inch viewing distance versus a thirteen inch viewing distance. The error rate was constant, with no variable having a greater effect on the error rate than did other variables. The expected error rate over all variables was .037 errors per each trial taken.

Prepared by:

FOREWORD

This experimental investigation was sponsored by G. E. Miller, Code 3400, Naval Electronics Laboratory, San Diego, California. The work was performed by the author in the Human Engineering and Man-Machine Systems Design Laboratory of the Naval Postgraduate School, Monterey, California

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I. INTRODUCTION

The investigation of new frontiers has always provided man with new discoveries and their associated problems. As man ventures forth into those lands under our seas, many new problems have emerged, one of which is the problem of human visibility in an underwater environment.

A great many variables contribute to the visibility of man underwater, whether the man be an amateur diving enthusiast, a commercial or military construction or salvage diver, or the operator of a submersible vehicle in which the man operates the vehicle from a flooded compartment area. Each of these types of people is required to read instrumentation of some type and the ease with which they can read will depend on how well the instrumentation was designed for underwater viewing.

Previous work by Duntley (1963), Kinney, Luria, and Weitzman (1967), and Luria and Kinney (1970) will amply provide the reader with an appreciation of underwater visibility problems. Optical problems, turbidity of the water, color of instrumentation, viewing distance, illumination levels, and many other variables can affect visibility of instrumentation.

Being cognizant of the many variables affecting underwater vision, the purpose of this research project was to investigate the effect of turbidity, viewing distance and color of instrument illumination on underwater vision with a primary orientation toward simulating vision in flooded submersible diving vehicle compartments.

II. EXPERIMENTAL PROCEDURE

The following is a description of the experimental apparatus, design, and subjects used in this research.

A. DISPLAY

The display used for this study was a Simpson 0-15 D. C. Voltmeter, model 1327, which has a rectangular illuminated surface with a 90 degree angular scale swept by a pivoting pointer. The numerals, indicia, and pointer were black on a white background.

1) Number Size

   Futura book style, with a height of 0.125''. Stroke width of .012'' or a stroke width to height ratio of 1:10.

2) Indicia Size

   Indicia had a width of .015'' for the major, .015'' for the intermediate and .005'' for the minor lines. The height was .155'' for the major, .117'' for the intermediate, and .094'' for the minor indicia lines.

The actual meter face was replaced by a 1:1 photographic reproduction. A negative 1:1 reproduction was also made to allow for further experimentation with an identical reverse image. At the same time, brightness was determined by measuring the reflectance of the white and black surfaces being used. The white background used in this experiment showed a reflectance of 20 percent and the black numerals showed a reflectance of 11 percent using white room illumination. (The relatively high black reflectance could be reduced in the future by use of a dulling spray to reduce glare.) The brightness contrast was 45 percent and the brightness ratio was approximately 2:1.

B. APPARATUS

In order to simulate the underwater environment, a rectangular tank (2' x 2' x 6') was constructed of 3/4" exterior grade plywood. A standard oval face mask was mounted in the center of one end. The tank was calked, sealed with a commercial yacht sealer, and inside painted black. The entire tank was then mounted on a frame of 2x4 pine with the center of the face mask 48 inches above the floor to allow subjects to be comfortably seated. The tank also had a lid to eliminate ambient illumination.

The test display, which was positioned inside a water tight 1/4" plexiglass box, was mounted in such a way that it was level with the face mask when placed inside the tank. Viewing distances of 8" and 13" were achieved by moving the entire display box back and forth inside the tank. White illumination of the display was accomplished with two General Electric number 44 6VDC bulbs located in the upper periphery. The green and red lighting conditions were obtained by placing Kodak Wratten gelatin filters around the bulbs. The red filter was a number 24 with spectral characteristic at 600 millimicrons. The green filter was a number 60 with spectral characteristic at 520 millimicrons.

A shutter was located between the face mask and the display to control the actual time of exposure to the subject. Timing, and shutter control were accomplished with a Lafayette Instrument Company Multi Reaction Timer, Model 6302 BX, coupled with a Lafayette Voice Time Control, Model 6602 A.

Reflectance of the photographic face was measured with a Weston Electrical Instrument Corporation light meter, model 756. This type of meter was chosen because it measures directly in footcandles. The same light meter was used to determine the voltages required to get the same apparent source intensity at the plexiglass/water interface for each of the three illumination colors. Thus, illumination coming from the meter face was held constant for each color used. The level of illumination was held at .5 footcandles, or .067 footlamberts which was identical to the lowest levels used by Beam and Shannon (1967).

The voltages to obtain .5 footcandle for the red, white, and green illumination colors were 2.5, 2.3, and 3.8 respectively.

Turbidity levels in the viewing tank were varied from clear tap water to mild to dark. Turbidity was achieved by using Nigrosin dye to discolor the tap water. Turbidity was measured by use of the attenuation coefficient (α) as described by Duntley (1963) and Luria and Kinney (1970). The units of the attenuation coefficient (α) used in the remainder of this paper are natural log units per meter. The attenuation coefficient for the different levels of turbidity was converted from the percent transmission measured on a monochromatic spectraphotometer with a 10 centimeter path. Readings were taken to correspond with the spectral characteristics of the Wratten filters. The range of attenuation coefficient for the three conditions, clear, mild, and dark may be seen in Table I. The spectraphotometer used was the "Spectronic 100" manufactured by Bausch and Lomb.

C. SUBJECTS

Seventeen subjects were used. All were military officer students at the Naval Postgraduate School. Subjects were selected on the basis of willingness and availability. None of the subjects wore glasses during testing. Volunteers who normally wore glasses either used contact lenses for 20/20 correction or were not accepted. No subject was color-blind. Subjects ranged in age from 24 years to 37 years.

D. EXPERIMENTAL DESIGN

The 18 conditions of the display reading task (3 illumination colors - red, green, white - by 2 viewing distances - 8" and 13" by 3 turbidity levels - clear, mild and dark) were presented to each subject in three periods, each lasting approximately 30 minutes and corresponding to one level of turbidity. The division of each subject's test into three periods was necessitated by class scheduling and was probably beneficial in reducing fatigue and/or boredom. The following conditions were used in establishing the test design:

1) Each subject received all 18 conditions. However, subjects were divided into six groups with each group receiving the turbidity levels in different sequences to prevent data biasing due to any possible learning effect for a given turbidity level.

2) Each condition was presented to a subject 10 times for a total of 180 trials which constituted a completed "data run" on a subject. A total of 3060 data points was obtained on the seventeen subjects.

3) Display readings for presentation to the subject were selected from a table of random numbers. Readings were normalized about 7.5 volts with equal division among numbers from 0 to 7.4 volts and 7.6 to 15 volts.

4) Subjects response times and errors were the criteria on which the variables were evaluated.

5) Variables held constant were: ambient illumination (which was total darkness), display size, display contrast, and apparent source intensity.

TABLE I

RANGE OF ATTENUATION COEFFICIENT (α)

Turbidity Level	Low		Mean		High	
	α	Trans.*	α	Trans.*	α	Trans.*
Clear	.18	83.5%	.53	58.9%	.61	54.3%
Mild	3.24	3.90%	3.92	2.00%	4.48	1.10%
Dark	5.29	0.50%	5.65	0.40%	6.69	0.10%

* Transmittance is the average transmittance through 1 meter of water for 520 and 600 millimicrons.

E. PROCEDURE

The test conductor had available to him the timing apparatus previously mentioned, a rheostat to control the display dial setting and a monitor voltmeter to ensure the proper display setting. A variac to control display illumination was also available but was only used to compensate for the changes in color to achieve identical apparent source intensity.

Each subject was given a set of written instructions, which may be found in Appendix A. In addition, each subject was given amplifying oral instructions on how the apparatus operated and what his response to the task was to be. Speed and accuracy were emphasized. The subject was then seated in a chair and the height adjusted so his face could rest comfortably in the mask. The shutter was then opened and the subject was allowed to study the display to become familiar with the indices and numerals. After the subject was satisfied, 20 trial readings were conducted to ensure familiarity with the procedure. Errors during the preliminary trial were shown to the subject to make him aware of the necessity for accuracy in reading the meter.

When the subject had been thoroughly prepared, a series of 60 readings were taken, 10 at each of the two distances for each of the three colors of illumination. Before each reading, the subject was given an audio warning.

Response times and errors were recorded manually by the test conductor.

III. RESULTS

Response times for each subject in each condition were averaged over the correct responses to yield one data point per subject per condition. These data were then analyzed with a 3x3x2 factorial Analysis of Variance (ANOVA). Table II summarizes the results of the ANOVA, and Appendix B summarizes the data.

No interactions were significant at any level. Color of illumination was significant at the .005 level and was investigated with the Duncan Multiple Range test. This showed no significant difference between white and green illumination while red varied significantly ($p < .05$) from both of the other colors, giving a longer response time. This result is illustrated in Figure 1. The mean response time under red illumination for all experimental conditions was 2.02 seconds, for green illumination 1.78 seconds. and for white illumination 1.76 seconds.

Turbidity was significant at the .05 level. In this case, mean response times were 1.74, 1.85, and 1.95 seconds for the clear, mild and dark turbidity conditions respectively. A range test of this data showed the clear condition to be significantly ($p < .05$) different from the dark condition. In other words, there was no abrupt jump in response times from clear to mild to dark turbidity levels but rather a continuous trend of increasing response time from the clear to dark conditions. See Figure 1.

TABLE II

ANALYSIS OF VARIANCE

RESPONSE TIMES

SOURCE	DF	SS	MS	F	p
TURBIDITY (T)	2	2.23	1.12	3.28	.05
COLOR (C)	2	4.14	2.07	6.09	.005
DISTANCE (D)	1	.48	.48	1.41	.25
T x C	4	.77	.19		NS
T x D	2	.64	.32		NS
D x C	2	.22	.11		NS
T x D x C	4	.16	.04		NS
ERROR	288	97.97	.34		
TOTAL	305	106.61			

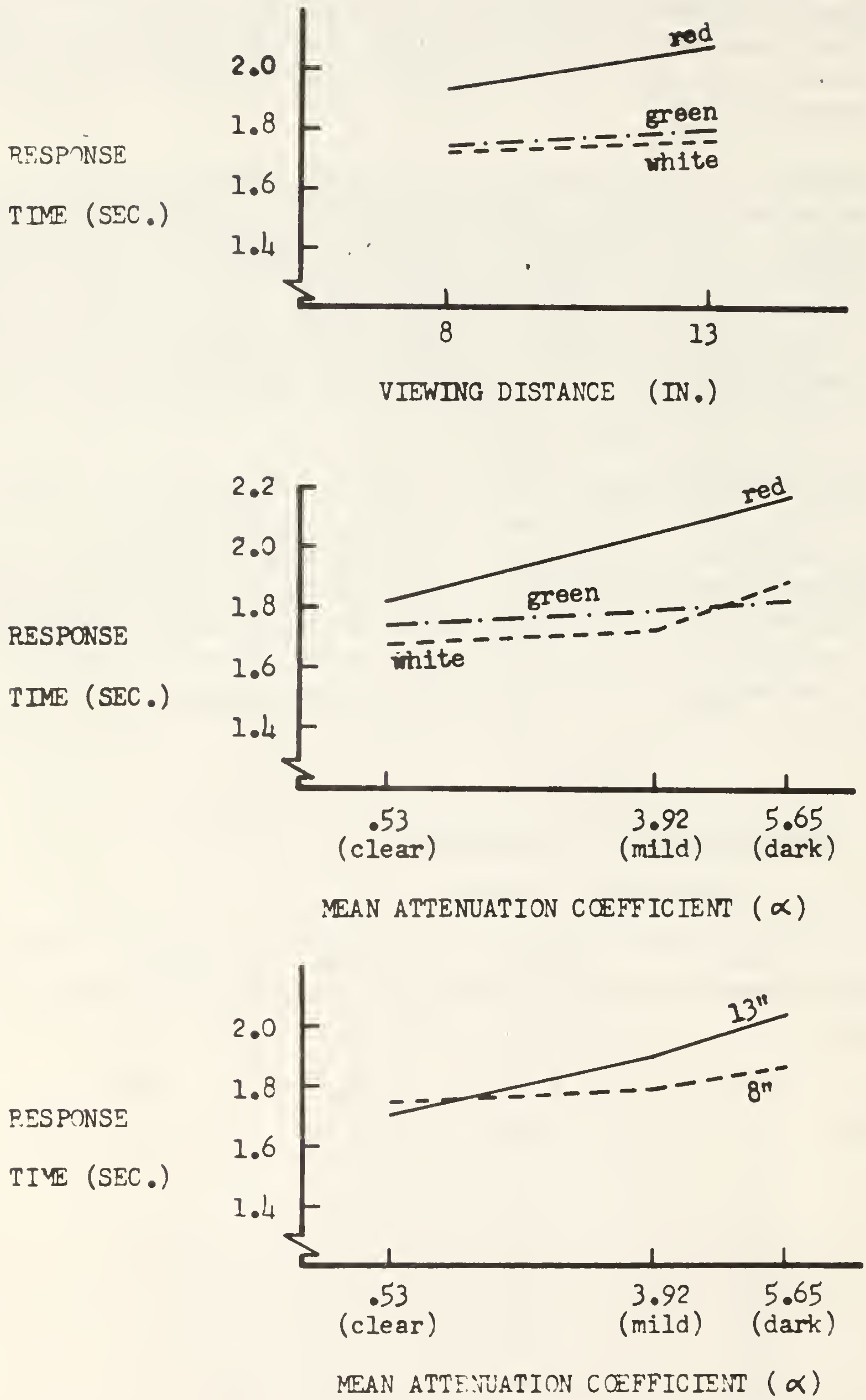

FIGURE 1. MEAN RESPONSE TIMES

Viewing distance was significant only at the .25 level with mean response times of 1.81 and 1.89 seconds for the 8 inch and 13 inch viewing distances respectively. This result is illustrated by Figure 1 .

Errors in response were designated as over estimation or under estimation and the amount noted. A non-parametric test of runs showed that over and under estimation occurred randomly. However, further examination of the errors showed that seventy-seven percent of the errors were of the magnitude of .2 volts. Since .2 volts was the smallest division made by the indicia on the meter face, the authors do not feel any of the .2 volt reading errors were really errors due to the following reasons. Because the viewing distances of 8 and 13 inches are very short, a parallax problem is present. The authors themselves viewed the meter display and it is quite obvious that one dominant eye could over ride the other eye, that a very slight movement of the head could give a .2 volt error, and that slight occlusion of either eye on a given trial could give a .2 volt error. Therefore, the remainder of the error analysis will be concerned with error readings of more than .2 volts. (However, for those who may wish to include errors of .2 volts, the mean error rate per trial observation for all types of errors was .159 and .163 for clear and mild turbidity, while the rate increased significantly ($p < .05$) to .217 for the dark turbidity condition. Illumination colors and viewing distance did not affect these error rates.)

In view of the above, the following error analysis is more realistic. Table III shows the distribution of errors with a magnitude of more than .2 volts over or under the correct meter reading. Observation of the error data by subjects showed they made either 0, 1 or 2 errors (most made no errors) during their ten trials under a given experimental condition. As such, the individual distribution of errors making up the totals in Table III can not be considered normally distributed and a chi-square test is more appropriate, as pointed out by Poock and Wiener (1966). If a given subject had provided many more errors than other subjects and thus caused an extreme positive skewness in one of the data cells, then a median test would be more appropriate. Therefore, chi-square tests on each of the groups of data in Table III showed no statistical dependence among any of the variables, and a Friedman non-parametric two-way analysis of variance also confirmed that the distributions of the errors under each variable were the same. There was no difference in the errors for 8 versus 13 inches, nor any difference in the errors for red versus green versus white illumination, nor any difference in the errors for clear versus mild versus dark turbidity levels. The average error rate to be expected is .037 errors per trial. The above results are illustrated in Figure 2 .

TABLE III

TOTAL ERRORS OVER .2 VOLTS

		Color		
		Red	Green	White
Turbidity	Clear	12	19	9
	Mild	13	11	11
	Dark	12	12	14

		Color		
		Red	Green	White
Distance	8"	19	15	18
	13"	18	27	16

		Distance	
		8"	13"
Turbidity	Clear	17	23
	Mild	19	16
	Dark	16	22

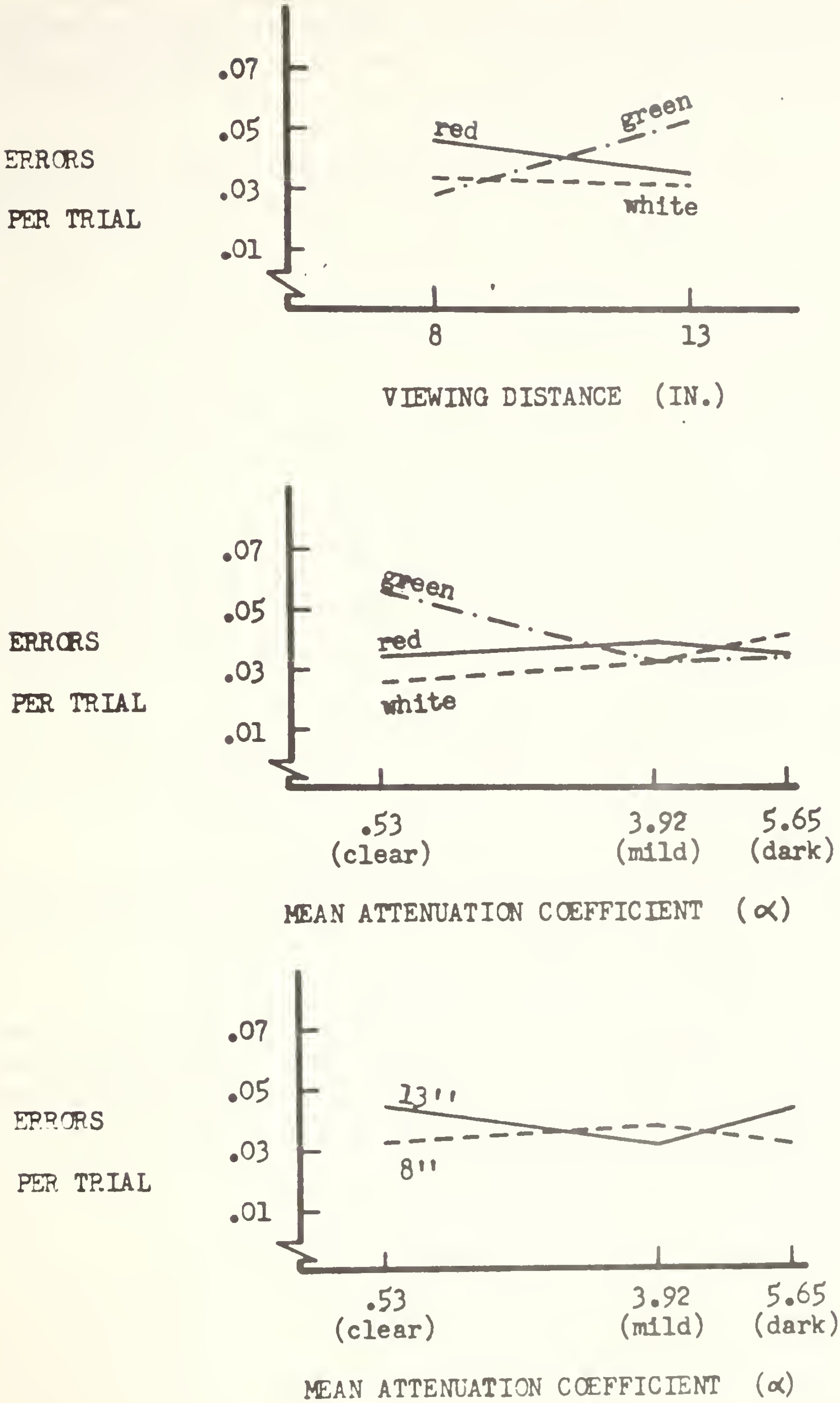

FIGURE 2. MEAN ERRORS PER TRIAL

IV. SUMMARY and DISCUSSION

The results of this investigation revealed that response time to read a display through water was fastest with white and green illumination and statistically slower when red was used to illuminate the display. This is different than the results of Beam and Shannon (1967) where they found red and green to provide the fastest response times. Since they used clear water but did not specify the transmittance of their water, and since tap water can vary greatly in transmittance, it would be somewhat unwise to compare their results to the clear condition of this experiment. However, a difference does exist and the difference could be due to the difference in the wavelength of the red illumination used in the two studies. The authors will be examining red illumination in the future to clarify the above results. The results of Kinney, Luria and Weitzman (1968), when using 8 inch colored targets, do not suggest the use of red in clear water conditions and agree with the results described herein, rather than those of Beam and Shannon for clear water.

Viewing distance was not extremely significant in this experiment and agrees with the results of Beam and Shannon (1967). Viewing distance, at least within the range of 8 to 13 inches, does not appear to be a crucial factor. Longer viewing distances may lead to stronger statistical differences than observed to date.

Turbidity of the water provided results as expected. One can expect longer response times to read a display as the water gets more turbid and the transmittance declines.

The error results of this experiment show a constant error rate over all conditions of .037 errors per trial. No variable had a statistically significant effect on the error rate.

It is suggested that future studies further examine the color variable for illumination, and begin to look at variable illumination levels controlled by the subject as well as longer viewing distances. Ambient illumination studies would follow after a solid foundation is established for color of illumination, viewing distance and turbidities.

APPENDIX A. INSTRUCTIONS TO SUBJECTS

You are acting as a subject to test responses to a visual stimulus underwater with various conditions of murkiness, viewing distance, and color of illumination.

Sit comfortably in the chair and place your eyes and nose in the face mask; no light should leak around your face and you will have to breathe through your mouth.

In front of you is a plastic shutter which will move to expose the stimulus - in your case a volt meter with a white face and black numerals and markings.

Your task will be to correctly read the meter and give a verbal report of what you saw. Your verbal response will cause the shutter to close. Avoid coughing, thinking out loud, or making any other noises which will cause the shutter to close before you are ready.

Do not remove your face from the mask until you are told to do so.

Work as quickly as possible but try to make your response accurate.

APPENDIX B. MEAN DATA VALUES FOR RESPONSE TIMES IN SECONDS

		TURBIDITY					
		Clear		Mild		Dark	
	Viewing Distance →	8"	13"	8"	13"	8"	13"
ILLUMINATION COLOR	Red	1.82	1.82	1.98	2.11	2.01	2.34
	Green	1.78	1.69	1.74	1.83	1.74	1.89
	White	1.70	1.65	1.68	1.78	1.84	1.89

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13. ABSTRACT

The purpose of this study was to determine the effects of illumination color, viewing distance, and turbidity on a visual reading task in a totally dark, flooded environment. The reading task was to read a voltmeter and make a correct oral report of the reading. A total of 180 data points spread over 18 viewing conditions were taken for each subject. Seventeen military officers were used as subjects. Experimental conditions were presented in a random manner to all subjects. As statistical examination of the results showed that white or green illumination is better than red in reducing reading response time. Turbidity levels were significant in affecting response time showing an increased response time as the Attenuation Coefficient (α) increased. There was no difference in the effect of an eight inch viewing distance versus a thirteen inch viewing distance. The error rate was constant, with no variable having a greater effect on the error rate than did other variables. The expected error rate over all variables was .037 errors per each trial taken.

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	ROLE	WT	ROLE	WT	ROLE	WT
Underwater Vision						
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